HAND-HELD MOISTURE METER CALIBRATIONS FOR SOME WEST COAST SOFTWOOD SPECIES

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INTRODUCTION

Hand-held moisture meters are commonly used in wood processing operations. There are two common types of hand-held meters, the conductance type (with pins) and the dielectric type (without pins). These meters are generically named after the particular electrical property measured in wood, and are used to estimate oven-dry basis moisture content (MC). There continues to be interest in how accurate common moisture meters are relative to the oven-dry basis MC (sometimes referred to as the "true" or actual MC).

The UC Forest Products Laboratory is involved in a study to evaluate operational characteristics of some relatively new meters and some meters that have been available for a number of years. Although the scope of the overall study will be reviewed here, this paper will only discuss a portion of the study currently being conducted. The objectives of the portion of the study discussed in this paper were to 1) determine the most appropriate "material density" setting for species being evaluated for a new dielectric-type meter, 2) determine the corrections for the meters and species investigated, 3) evaluate the relative accuracies of the meters, and 4) evaluate the effect of density on moisture meters.

EXPERIMENTAL

Two conductance-type and two dielectric-type hand-held moisture meters were used in this study. The conductance-type meters included the Delmhorst RDX-1 and the Brookhuis FMD Plus (at the time of this writing, the Brookhuis meter is no longer commercially available in the United States). Results obtained using the Brookhuis meter will not be discussed in this paper, but will be reported in a subsequent publication. The dielectric-type meters included the Wagner L-600 and the Doser Type H-24.

Six species were included in the larger study. These included redwood (*Sequoia sempervirens*), ponderosa pine (*Pinus ponderosa*), sugar pine (*Pinus lambertiana*), white fir (*Abies concolor*), incense cedar (*Calocedrus decurrens*), and Douglas-fir (*Pseudotsuga menziesii*). The Douglas-fir samples included material obtained from five geographic locations, including Arizona, California, Montana, Oregon, and Washington. This paper will limit discussion to sugar pine, incense cedar, and redwood.

Matched samples, 5.5 in. wide x 5.5 in. longitudinally, were cut from 15 boards for each species group (only 12 boards were used for the Douglas-fir obtained from Montana, Oregon, and Washington). Two thicknesses, 0.75 in. and 1.5 in., were investigated. One matched sample from each board was put in an environmentally controlled conditioning rooms or cabinet maintained at nominal equilibrium moisture content (EMC) conditions of 18%, 15%, 12%, 9% or 6%. Since there were 12 to 15 boards per species group serving as replications, a complete set consisted of between 120 and 150 specimens (12 or 15 samples x 5 conditions x 2 thicknesses). All tests were conducted at a nominal temperature of 70 F. Except in the case of the samples conditioned in a controlled environment cabinet at 15%, all testing was conducted in the room where MC equalization took place. The specimens which were equilibrated in the cabinet were tested in an uncontrolled laboratory, but laboratory temperatures during the day were typically about 65.

One-inch specimens were cut between each of the 5.5 in. x 5.5 in. samples. These one-inch specimens were used to estimate the relative density (oven-dry mass, swollen volume). The one-inch specimens on one side of a given 5.5 x 5.5 in. sample were used to calculate an average value for each sample.

All samples were tested using a one-inch thick piece of styrofoam insulation as a testing substrate. This was done to assure that the meter only responded to the wood specimen. MC data was obtained from with the Doser meter using all meter "material density" settings (from "0" through "10"). For purposed of data analysis, each group of these readings was treated as a separate meter. The Delmhorst meter was operated using the "Douglas-fir" setting (the "A" on the species selection dial) . The Wagner L-600 meter reading was used without adjustment.

RESULTS AND DISCUSSION

Analysis of Variance Results

One-way analysis of variance was initially conducted on the actual, or "true" MC, relative density, and thickness data to test certain hypotheses. The first analysis of variance test was conducted between the actual MC and the nominal EMC to determine whether an adequate spread in MC values was obtained during specimen equalization. In each case, there was a clear and significant ($p\text{-value} < 0.05$) difference between samples at each nominal EMC condition. The second analysis of variance test was conducted between relative density data and nominal EMC groups. The relative density data consistently tested to be the same between nominal EMC groups ($p\text{-value} > 0.9$). This test was more critical than the first one, since in order to adequately evaluate meter dependence on relative density using traditional statistical methods (i.e., tests based on normal distribution theory) , variation in relative density between EMC groups must be small (and actual differences statistically insignificant). The final analysis of variance was conducted between thickness and actual MC. Differences between thickness and actual MC were insignificant ($p\text{-value} > 0.8$). Therefore, for the regression analysis, both thickness data sets were combined.

Linear Regression Results

Regression analysis was conducted on the moisture meter data collected for sugar pine, redwood, and incense cedar. The simple linear regression analysis used the moisture meter data as the dependent (y) variable and the actual MC as the independent (x) variable. For the multiple regression analysis, the relative density

Table 1. R^2 and SEE results for sugar pine, redwood and incense cedar. Results for the dielectric-type Doser meter were obtained using the "2" material density setting.

Species	Meter	Statistic	Simple Regression	Multiple Regression
Sugar pine	Delmhorst	R^2	0.90	0.90
		SEE	1.37	1.36
	Wagner	R^2	0.89	0.92
		SEE	1.79	1.54
	Doser	R^2	0.90	0.96
		SEE	1.33	0.88
Redwood	Delmhorst	R^2	0.89	0.90
		SEE	1.28	1.20
	Wagner	R^2	0.76	0.93
		SEE	1.86	1.01
	Doser	R^2	0.74	0.94
		SEE	1.87	0.83
Incense cedar	Delmhorst	R^2	0.78	0.78
		SEE	1.69	1.69
	Wagner	R^2	0.88	0.91
		SEE	1.29	1.13
	Doser	R^2	0.90	0.97
		SEE	0.91	0.53

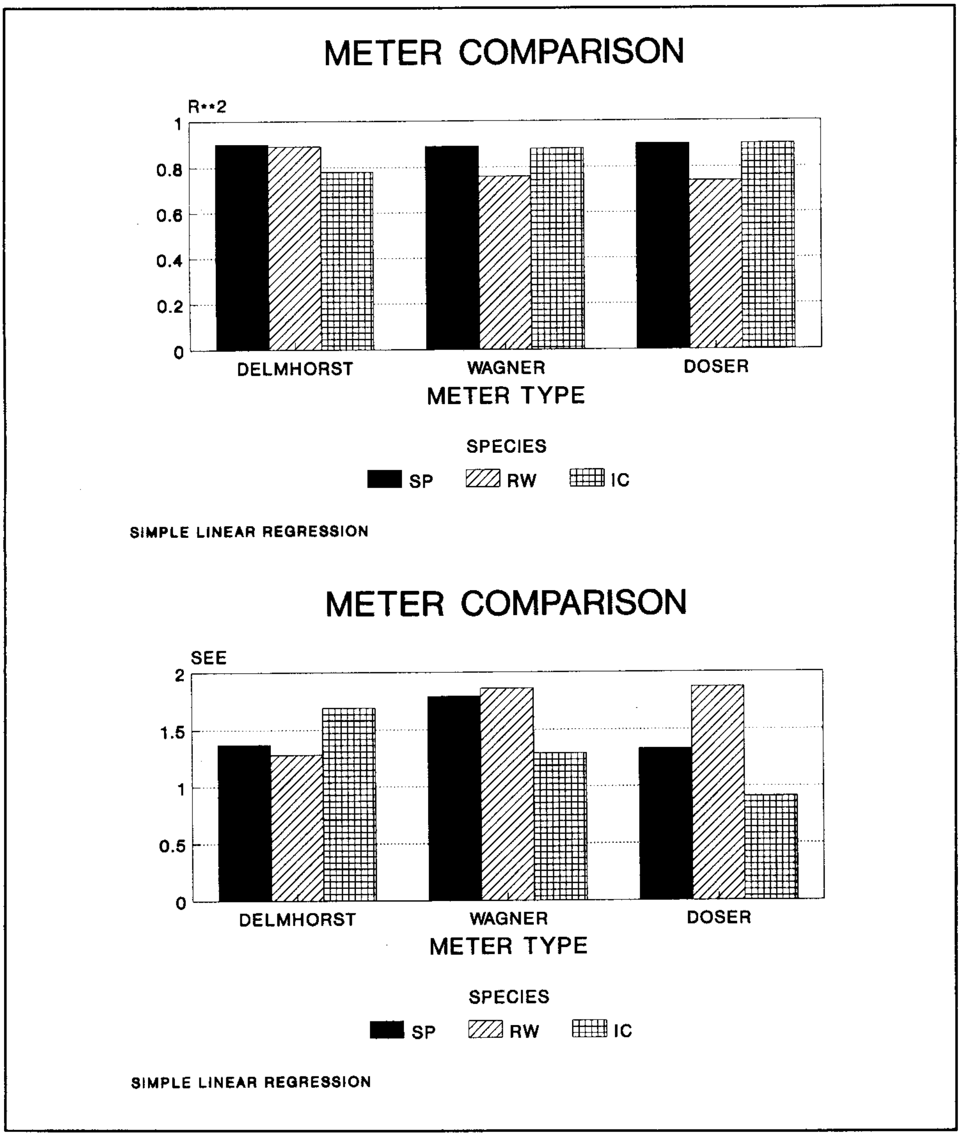

Figure 1. Comparison of conductance- and dielectric-type meters.

was added as an additional independent variable. Statistical measures used to evaluate the results of the regression analysis for sugar pine, redwood, and incense cedar are given in Tables 1. In each table, a measure of the goodness of fit of the regression is given by the coefficient of determination, R^2. The standard error of the estimate (SEE), a measure of the meter accuracy , is also included in the table.

As seen in this table, with the conductance meter, there is essentially no difference between the simple and multiple regression results.The R^2 is fairly high (0.90) for sugar pine and redwood, and somewhat lower (0.78) for incense cedar.The standard error of the estimate is relatively low when the R^2 is high. For both dielectric-type meters, the results are consistently better (higher R^2 and lower SEE) for the multiple regression analysis (meter reading versus actual MC and relative density) relative to the simple linear (meter reading versus actual MC). These differences, however, are species and meter dependent, with average improvements in R^2 ranging from 8% for sugar pine and incense cedar, to 34% for redwood. Improvements in SEE were typically larger, ranging from 24% for sugar pine and incense cedar, to 41% for redwood. These findings are in general agreement with published research regarding the influence of density on the performance and accuracy of moisture meters (James 1988, Milota 1991, Quarles and Breiner 1989).

A comparison of the moisture meters based on R^2 and SEE values are presented graphically in Figure 1. Only the simple linear results are given since the standard test methods given in ASTM D-4444 (1989) designate this as the appropriate procedure. These results indicate that, when averaged over all species, the conductance- and dielectric-type meters perform about the same.

The results of the simple linear regression analysis is summarized in Table 2. The Doser meter results are based on measurements made using the number 2 material density setting. The slope and y-intercept data given in this table can be used to determine correction tables using the procedure outlined in the next section.

Table 2. Slope and y-intercept data determined from regression analysis on three hand-held moisture meters and three species.

Species	Meter	Slope, m	Y-intercept, b
Sugar pine	Delmhorst	0.81	0.55
	Wagner	0.74	-1.00
	Doser	0.71	3.76
Redwood	Delmhorst	0.71	3.28
	Wagner	0.88	-2.51
	Doser	0.70	3.01
Incense Cedar	Delmhorst	0.59	3.55
	Wagner	0.70	4.24
	Doser	0.76	-1.44

Procedure to Determine Doser "Material Density" Setting

The results for the simple linear regression data collected for sugar pine using the Doser moisture meter at "material density" settings from 0 to 5 are given in Table 3. Above the number 5 setting, the meter readings tended to be off-scale, and so these sets of measurements have been eliminated from the analysis. The regression results in Table 3 are good over a range of settings, especially with settings from 0 to 3. If only R^2 and SEE were used to select an appropriate "material density" setting, then one could be indifferent to a setting between 0 and 3.

Table 3. R^2 and SEE results for Doser "material density" settings for sugar pine.

Doser Setting	R^2	SEE
0	0.91	1.12
1	0.91	1.28
2	0.92	1.23
3	0.92	1.22
4	0.89	1.65
5	0.89	1.51

In order to develop a systematic approach to determine the "best" material density setting, moisture meter correction tables were developed for each set of measurements made using material density settings from 0 to 5. Correction tables were developed using the regression equations from the linear regression analysis between the meter reading and the true MC. The simple regression equation takes the form of Equation 1. Equation 1 is rearranged to solve for the true MC (Equation 2). Finally, the correction for a given moisture content (i.e., the number that should be added or subtracted to the meter reading to obtain the true MC) is determined by difference (Equation 3).

$$MC_{meter} = m(MC_{true}) + b \qquad (1)$$

where m = slope
b = y-intercept

$$MC_{true} = (MC_{meter} - b)/m \qquad (2)$$

$$\text{Correction} = MC_{meter} - MC_{true} \qquad (3)$$

Table 4. Absolute value and standard deviation of the average correction for the Doser "material density" settings.

Doser Setting	Mean Correction	Standard Deviation
0	3.13	2.06
1	1.84	1.28
2	1.84	1.32
3	3.23	1.83
4	4.93	1.05
5	6.54	0.85

Table 5. Correction values for the Doser meter, at the number 2 "material density" setting, sugar pine. The "meter correction" is added to the meter reading to obtain an estimate of the "actual MC"

Meter Reading	Actual MC	Meter Correction
6	4.4	-1.6
7	5.8	-1.2
8	7.2	-0.8
9	8.7	-0.3
10	10.1	0.1
11	11.5	0.5
12	12.9	0.9
13	14.4	1.4
14	15.8	1.8
15	17.2	2.2
16	18.7	2.7
17	20.1	3.1

The absolute value of the correction at each meter reading (indicating MC), for each of the Doser "material density" setting, was then calculated. The results of this analysis are given in Table 4. It is clear from this table that if your aim is to minimize the correction, which is added to or subtracted from the meter reading to obtain the true MC, then the most appropriate Doser "material density" setting for sugar pine would either be 1 or 2. If, however, your goal was to consistently add or subtract the correction (but not both), then the most appropriate setting would be different, but could be determined in a similar way. The correction table for the Doser meter, number 2 "material density" setting, for sugar pine, is given in Table 5.

SUMMARY

1. The Doser meter was insensitive to minor changes in the "material density" setting.
2. The most appropriate Doser meter "material density" setting for sugar pine, redwood and incense cedar was number 2. The material density setting partially corrected for species differences, an additional species correction would still be required (as evidences in Figure 5.)
3. Differences were apparent between the conductance- and dielectric-type meters evaluated, however, on average they exhibited similar accuracy.

REFERENCES

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